Improved Parameterizations Of Nonlinear Four Wave Interactions For Application In Operational Wave Prediction Models

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LONG-TERM GOAL

The long-term goal of this project is to improve spectral wave prediction models by providing an accurate and fast method for computing the nonlinear four wave interactions in deep and shallow water. Although an accurate integral description of these interactions exists for more than 27 years (Hasselmann 1962, see also Zakharov, 1998), the computation thereof is hampered by the complexity of its functional form and its computational demands. In 1985 the Discrete Interaction Approximation (Hasselmann et al., 1985) was developed which enabled the development of third generation wave prediction models. The DIA, however, has some shortcomings which hamper the further development of third generation wave prediction models, see Figure 1. These models all use the action balance equation for describing the time and space evolution of wave spectra. By providing an accurate and fast method for computing these interactions, wave evolution characteristics will improve and more attention can be given to the development of the other terms.

OBJECTIVES

The objective of this project is obtain a fast and accurate method for computing the nonlinear four wave interactions in deep and shallow water, such that this method can be applied in operational wave prediction models.

APPROACH

To develop improved methods for computing the nonlinear four wave interactions, a bench mark model will be developed for comparing any approximation for correctness and/or calibration. This benchmark model will be based on the method of Resio and Tracy (Resio and Perrie, 1991). The software for computing the nonlinear four wave interactions will be rewritten such that it can easily be included into any spectral wave prediction model. At the same time, approximate methods will be developed by following two paths. The first path is based on stripping down the method of Resio and Tracy by reducing the integration space and developing smart integration techniques. The second path is based on extending the DIA by including more basic wave number quadruplets. In the development of these approximations attention will be given to the following aspects:

- improve the depth scaling (Herterich and Hasselmann, 1980),
- swell-sea interaction,
- effect on the width of spectrum, both in frequency and direction space,
- short and long time scale behavior,

- fetch and time evolution of spectra,
- directional response to turning winds.

For testing the time and fetch behavior of the evolution of wave spectra a one-dimensional transect wave model will be used. This model will be used for the analysis of wave transformation of idealized cases but also to the evolution of wave spectra on the continental shelf near Duck as observed in the SHOWEX experiment.

WORK COMPLETED

The AWPP Snl group (Herbers, Jensen, Resio, Tracy, Van Vledder and Zakharov) met two times during the year for in-depth discussions, and to plan future collaborative work. It was agreed that the exact methods are based on the Resio-Tracy method, and that the exact solution will be implemented into existing wave prediction models, WAM (Jensen and Resio) and SWAN (Van Vledder). Further, alternative representations of the nonlinear transfer will be developed to replace the DIA, such as the diffusion operator (Zakharov) and extensions to the DIA (Van Vledder).

Benchmark tests have been carried out with two exact methods for computing the nonlinear interactions for a given wave spectrum. The models used were the EXACT-NL model of Hasselmann and Hasselmann (1981) and the method of Resio and Perrie (1991). It turned out that these models give similar results for a wide range of spectra within the accuracy that can be expected from the model results.

The Resio-Tracy code has been rewritten in the form of a set of subroutines. This new source code has been tested and verified against the original Resio-Tracy. For inclusion into an arbitrary spectral wave model, an interface routine must be set up for each 'mother' model. These interface routines take care of the proper spectral transformations and order of the loop structure. Such a routine has been made and tested for the SWAN wave prediction model (Booij et al., 1999). Initial tests have been carried out with the SWAN model with the exact method for computing the nonlinear four wave interactions.

A re-normalization technique has been formulated to scale approximate methods with respect to the exact solution.

RESULTS

A set of subroutines has been developed for the exact computation of the nonlinear interactions in an arbitrary wave spectrum. In rewriting the Resio-Tracy code, some improvements have been realized. Further, the code has been formulated in such a way that it provides a good starting point for the further development of fast and accurate parameterizations. In addition, an interface routine for the SWAN model has been created and implemented in the SWAN model.

Tests have been carried out with the SWAN model, including the above described set of subroutines. These tests indicate that incorporation of the exact nonlinear interactions, as opposed to using the DIA, improves the resulting directional spreading and the iteration behavior of the SWAN model.

The new code is capable of computing the nonlinear interactions for any water depth, and for either spectra given in a bounded symmetric of non-symmetric sector or for a full circle. In addition, various options have been included to switch between different dispersion relations and/or coupling coefficients.

A transect model has been developed for modeling the evolution of the wave field along a one-dimensional fetch. Some further testing is needed to make generally applicable.

IMPACT/APPLICATIONS

A fast and accurate method for computing the nonlinear four wave interactions will improve the quality of operational third generation wave prediction models. By providing an accurate method for computing these interactions, the basic growth behavior improves and more attention can be given to the other source terms in third generation wave prediction models. Since the source term balance will change by replacing the DIA with better methods, third generation wave prediction model need to be re-calibrated.

TRANSITIONS

The set of subroutines for computing the nonlinear four wave interactions will be made available to the wave modeling community to be included in wave prediction models. The only model dependent part will be the interface subroutine, which also ensures that future versions can easily be included in the wave models. In addition, the one dimensional transect model will be made available for researchers who want to study the fetch or time evolution of wave spectra.

RELATED PROJECTS

Delft University of Technology: The continued development of the third-generation shallow water wave model SWAN.

Naval Postgraduate School, Monterey: Improved parameterization of nonlinear wave interactions for application in operational wave prediction models.

USAE Waterways Experiment Station, Coastal and Hydraulics Laboratory: Accurate representation of arbitrary depth source terms in coastal wave prediction models.

REFERENCES

Booij, N., L.H. Holthuijsen and R.C. Ris, 1999: A third-generation wave model for coastal regions. 1. Model description and validation. J. Geophys. Res., Vol. 104, No. C4, 7649-7666.

Hasselmann, K., 1962 Hasselmann, K., 1962: On the non-linear transfer in a gravity wave spectrum, 2, Conservation theory, wave-particle correspondence, irreversibility, J. *Fluid Mechanics*, Vol. 15, No. 385-398.

Hasselmann, S., and K. Hasselmann, 1981: A symmetric method of computing the nonlinear transfer in a gravity wave spectrum, Hamburger. Geophys. Einzelschr., A, 52, 138 pp.

Herterich, K., and K. Hasselmann, 1980: A similarity relation for the nonlinear energy transfer in a finite-depth gravity-wave spectrum. J. Fluid. Mech., Vol. 97, 215-224.
Hasselmann, S., K. Hasselmann, J.H. Allender and T.P. Barnett, 1985: Computations and parameterisations of the nonlinear energy transfer in a gravity wave spectrum. Part 2: Parameterisations of the nonlinear energy transfer for application in wave models. J. Phys. Oceanogr., Vol. 15, 1378-1391.
Resio, R.T., and W. Perrie, 1991: A numerical study of nonlinear energy fluxes due to wave-wave interactions. Part 1: Methodology and basic results. J. Fluid Mech., Vol. 223, 609-629.
Zakharov, V.E, 1998: Statistical theory of gravity and capillary waves on the surface of the finite-depth fluid. Proc. UITAM symposium (Nice, 1998), special issue of the European Journal Mechanics.

PUBLICATIONS

Van Vledder, 1999a: Source term investigation SWAN, ALKYON report A162.

Van Vledder, G.Ph. van, T.H.C. Herbers, R. Jensen, D. Resio and B. Tracy, 1999: Modeling of nonlinear quadruplet wave-wave interactions in operational coastal wave models. Abstract accepted for presentation at ICCE 2000.

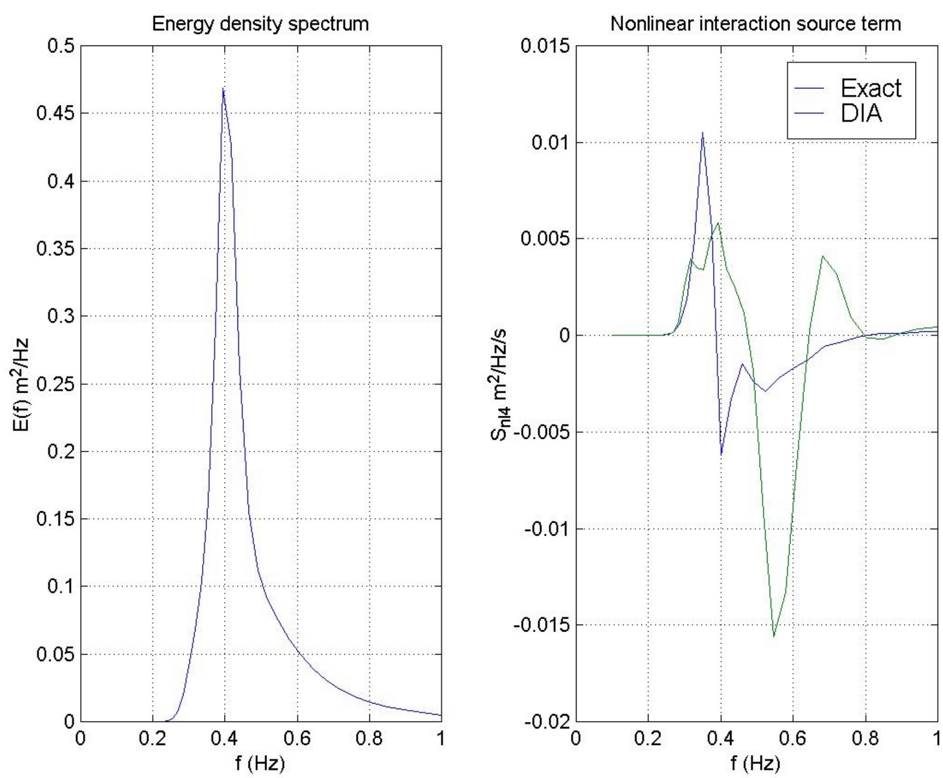

Figure 1: Comparison of the nonlinear interaction as computed by the Resio-Tracy method and the Discrete Interaction Approximation for a JONSWAP spectrum with a peak frequency of 0.4 Hz.